Renewable and Sustainable Energy Reviews 20 (2013) 504–513

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis

Bianca van der Kroon*, Roy Brouwer, Pieter J.H. van Beukering

Department of Environmental Economics, Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 15 November 2011
Received in revised form
12 November 2012
Accepted 19 November 2012
Available online 12 January 2013

Keywords:
Energy ladder
Energy transition
Fuel choices
Meta-analysis
Household decision environment

ABSTRACT

Modern fuels are an important enabler of social and economic development. Still, over 2 billion people rely on traditional biomass for their daily energy needs. To overcome the negative effects of traditional energy on human health and the environment and to enhance the livelihood conditions of the poor, a transition towards cleaner and more efficient forms of energy is needed. Understanding household fuel choice and fuel switching behaviour is of vital importance in search for policies to support such a transition process. This paper adds to the existing energy transition literature in two ways. First, we provide a novel conceptual framework to analyze the decision environment underlying energy and fuel choices. Second, we apply this framework in a meta-analysis of existing choice models investigating energy switching and stacking behaviour in urban and rural areas in developing countries. The meta-analysis shows that socio-economic household characteristics appear to receive most attention so far in identifying groups of fuel users, while relatively little information is available on the impact of the external decision context on household energy choices.

Contents

1. Introduction

Over 2 billion people in developing countries rely on traditional biomass fuels – wood, agricultural residues and dung – for their daily energy needs. In many countries, these resources account for over 90% of household energy consumption [1]. The use of biomass fuels in inefficient and traditional ways can have severe implications for human health, the environment and economic development [2]. The collection of biomass fuels is not only a time consuming task constraining especially women to engage in income generating activities, it also causes serious health problems due to the carried heavy loads and indoor air pollution. With a person's productivity being proportional to his or her health status, the use of biomass fuels restricts people's economic contribution [3]. Women and children are often the ones who spend most time and effort on cooking and collecting

* Corresponding author. Tel.: +31 20 5983546; fax: +31 20 5989553.
E-mail address: bianca.van.der.kroon@ivm.vu.nl (B. van der Kroon).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.11.045

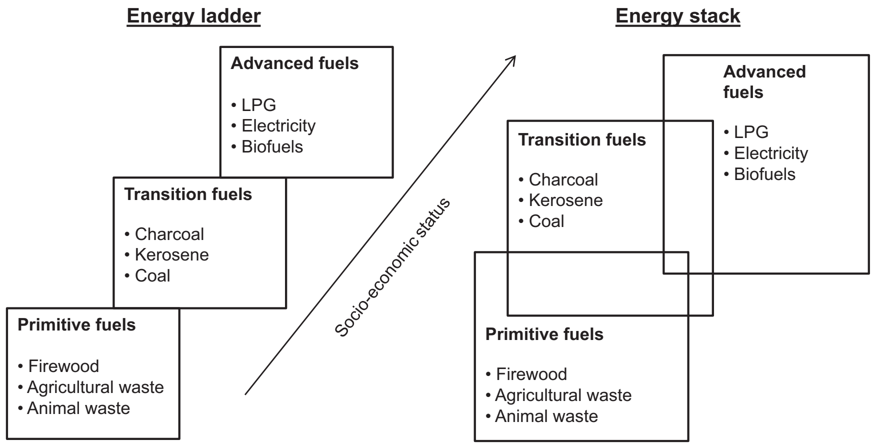


Fig. 2.1. The energy transition process [14].

firewood and are therefore most prone to the negative impacts of the use of biomass fuels [2]. Environmental concerns of biomass use focus on deforestation, land degradation and air pollution [1].

To overcome these negative effects and enhance the livelihood situation of the poor, a transition towards cleaner and more efficient forms of energy is needed. Understanding household fuel choice and fuel switching is of vital importance in search for policies to support this transition process. A common model to describe household fuel choices in developing countries is the "energy ladder" which ascribes differences in energy-use patterns between households to variations in economic status [4–6]. Existing research, e.g. [7–14] has focused on describing household behaviour in light of energy transitions and tried to identify determinants driving household energy choices beyond income.

This paper contributes to the existing literature in two ways. First, we provide a more comprehensive framework based on farm household market participation decision-making in transition and developing economies to analyze the decision environment underlying fuel choices. Second, we apply the framework in a meta-analysis of existing choice models investigating energy switching and stacking behaviour in urban and rural areas in 12 different developing countries in Africa, Asia and Latin America. The main objective of the paper is to identify the key factors explaining energy transition processes based on the developed framework underlying household energy choices. The assessment of energy transition models is accompanied by a critical review of existing knowledge and information gaps.

The remainder of this paper is organized as follows. Section 2 introduces the energy ladder model and discusses the empirical reality of the ladder. Section 3 introduces the general framework underlying the household decision-making environment related to energy choices. In Section 4 the drivers of the energy transition are reviewed in a qualitative meta-analysis. The paper concludes with a discussion of unresolved issues and essential focal points for future research in Section 5.

2. The energy ladder

The energy ladder model assumes households to mimic the behaviour of a utility maximising neoclassical consumer, which implies that they will move to more sophisticated energy carriers as their income increases [4]. Fuel switching is a central concept in the energy transition process, referring to the displacement of one fuel by another. A move up to a new fuel is simultaneously a move away from the fuel used before [2]. The fuels on the energy ladder are ordered according to the household's preferences based on physical characteristics, including cleanliness, ease of use, cooking speed, and efficiency [12].

The process of climbing the energy ladder is described by a linear movement with three distinct phases (see the left hand side in Fig. 1). As families gain socio-economic status they abandon technologies that are inefficient, less costly and more polluting and move from universal reliance on biomass fuels to transition fuels such as kerosene, coal and charcoal in the second phase. In the third and last phase, households switch to fuels such as LPG and electricity [10]. Higher ranked fuels are usually more efficient and costly, but require less input of labour and produce less pollution per unit of fuel [7]. "*The energy ladder also assumes that more expensive technologies are locally and internationally perceived to signify higher status. Families desire to move up the energy ladder not just to achieve greater fuel efficiency or less direct pollution exposure, but to demonstrate an increase in socioeconomic status*" [[7]: 2084].

The energy ladder model portrays wood as an inferior economic good, i.e., the fuel for the poor. This implies a strong correlation between income and fuel choice. Cross-country comparisons reveal a positive correlation between economic growth and modern fuel uptake, suggesting that "*as a country progresses through the industrialization process, its reliance on petroleum and electricity increases and the importance of biomass decreases*" [[4]: 347]. On a micro-level, empirical studies have confirmed the relation between income and fuel choice too [4,11,15,16]. However, empirical evidence suggests that the linkages between fuel choice and income level are rarely as strong as assumed by the energy ladder. Both Arnold et al. [17] and Cooke et al. [18] note that many estimated income elasticities of demand for fuel wood are insignificant, very low or even positive. Studies in developing countries show that fuel wood can be an important energy source for both urban and rural households at all levels of income [12,19–22]. For example, Hiemstra-van der Horst and Hovorka [12] find that in Maun, Botswana, despite common use of commercial alternatives, fuel wood is chosen by households across the income spectrum. At the same time there are also numerous examples of low income households using advanced modern fuels such as electricity and LPG [8,15,21]. However, these studies were all conducted in urban locations and may therefore not be representative for rural households.

Energy use patterns of the rich and poor are certainly not identical. The per capita modern fuel consumption among high income households is far greater than that of low income households [23]. However, the above suggests that the "*characterization of wood energy as the "fuel of the poor" is an oversimplification*" [[12]: 3336]. It also suggests that a broader spectrum of influential factors besides income should be considered.

2.1. Energy stacking

A growing body of empirical studies on household energy use show that the energy transition does not occur as a series of simple, discrete steps; instead, multiple fuel use is more common [5,8,10,15,17,21,24,25]. With increasing income, households adopt new fuels and technologies that serve as partial, rather than perfect substitutes for more traditional ones [23]. Furthermore, fuel switching is not unidirectional and people may switch back to traditional biomass even after adopting modern energy carriers [7,17,26]. Wickramasinghe [27] finds households in semi-urban areas of Sri Lanka who already had adopted LPG to revert to fuel wood after a high increase in LPG prices. These empirical observations have led to the development of alternative models to describe the energy transition process.

Foley [28] argues that it is a ladder of energy demand rather than fuel preferences that determine fuel choice. Energy demand is driven by the services energy provides. At a subsistence level households rely on biomass fuels for cooking and heating, which form the main energy needs at that stage of development. With increasing income, the household can afford to purchase a variety of appliances, each of which requires a specific energy source. This leads to a more diversified energy demand including modern energy sources. For basic energy needs households will continue to use biomass fuels and add fuels to accommodate the needs for their changing lifestyle [12].

Masera et al. [7] go a step further and suggest that there is no such thing as fuel switching and propose a multiple fuel model. Instead of switching fuels, households choose to consume a portfolio of energy options at different points along the energy ladder. The fuel portfolio of households can represent a combination of fuels from both lower and upper levels of the ladder. The process of households using multiple fuels at the same time is termed fuel stacking (see the right hand side in Fig. 2.1). Masera et al. [7] find in their study that it is "*unusual for households to make a complete fuel switch from one technology to another; rather they begin to use an additional technology without abandoning the old one*" (ibid: 2085). For example, households in Jaracuaro in Mexico add cooking fuels such as LPG and stove types, but rarely abandon fuel wood completely.

When comparing Foley's energy demand model to Masera's multiple fuel model, they appear to be similar at first sight. An important distinction is, however, Masera's observation that for a particular purpose, such as cooking, multiple fuels are used. Hence, it is not necessarily the case that we only see multiple fuel use due to an increase in the variety of appliances available to the household.

The multiple fuel model is gaining increasing support in the literature, e.g. [2,10,12,13,22]. Several complementary reasons have been put forward to explain fuel stacking behaviour by households in both urban and rural areas. First, Davis [15] argues that fuel stacking is inherent to the poor's livelihood strategies. Irregular and variable income flows of households (derived from agricultural work or informal selling of goods) prohibit the regular consumption of modern energy. Therefore, specific budget strategies are applied in order to maximize fuel security. Second, fuel stacking behaviour is observed due to fuel supply problems [7,19,29,30]. The supply of modern fuels is erratic and the reliability of supply channels low. Therefore, households must have one or two fuels which can be used as backups in the event that their primary fuels are temporarily unavailable [19]. Third, fluctuations of commercial energy prices might make the preferred fuel temporarily unaffordable [19]. Finally, culture and traditions also play a role in constraining a complete transition to modern fuels. Traditional methods of cooking are often rooted in local cultures preventing the use of modern fuels [7,31]. Thus, "*multiple fuel use patterns in households are the result of complex interactions between economic, social and cultural factors*" [[7]: 2004].

Heltberg's [2] finding in Guatemala provides food for thought. The inverted U shape found for the number of fuels used for cooking in urban areas implies that during the development process the uptake of modern fuels shows a fuel stacking pattern but at the top end several traditional fuels are displaced indicating fuel switching. This may be an indication that fuel stacking is a transient phenomenon rather than a linear and continuous process. Studies in rural areas have not found such results and report only partial switching behaviour along income segments [13,22]. Fuel wood remains a very important energy source irrespective of household income.

Both the energy ladder and the energy stacking model rely heavily on a universal hierarchy of fuels and services [32]. This hierarchy is based on product specific characteristics of respective fuels. The transition process is described by moving to the most desired and "best" fuel available. These models do not take into consideration sustainability aspects in their methods of ranking the fuels and focus entirely on conventional forms of energy. Pushing the energy transition process solely towards (non-renewable) conventional sources of energy is non-sustainable in the long run as the resources on which this process depends are depleting at a high rate [33]. Exergy analysis[1] provides a method of comparing conventional and renewable forms of energy in a systematic manner incorporating both quality and quantity aspects of energy and taking into account the impact of resource use on the environment [33]. Moreover, exergy clearly identifies efficiency improvements and reductions in thermodynamic losses attributable to more sustainable technologies [34]. This stresses the importance of considering both fuel and conversion technology, leading to a better understanding of their interaction. Instead of pushing all societies and households in one direction, e.g., the top rank of the energy ladder, using exergy analysis can thus provide us with a much broader and diversified view of transition alternatives and their relation to one another.

3. Towards a comprehensive framework for modeling household energy choices

The literature has shown that one needs to look beyond income to explain household energy choices. A myriad of factors shape the environment in which households make their decisions. We refer to such an environment as the 'household decision environment', representing a complex and interactive web of factors that influence behaviour. Here we make use of the framework developed by Bruntrup and Heidhues [36] to structure and describe the decision environment (see Fig. 3.1). They describe a decision environment for market participation by farm households in developing and transition economies. Their framework focuses on the choice between subsistence and market orientation, i.e., the degree of market integration, where subsistence orientation refers to a farmer who predominantly produces for his own family's consumption. In a developing country context, the choice between self-sufficiency and market dependence plays an important role in the choice for energy carriers as well. As the energy ladder shows, households at the bottom of the

[1] The exergy of an energy form or a substance is a measure of its usefulness or quality. Exergy is based on the first and second laws of thermodynamics, and combines the principles of conservation of energy and non conservation of entropy. Exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Exergy analysis in turn is a methodology used for the analysis, design, and improvement of energy and other systems as well as for enhancing environmental and economic performance [35].

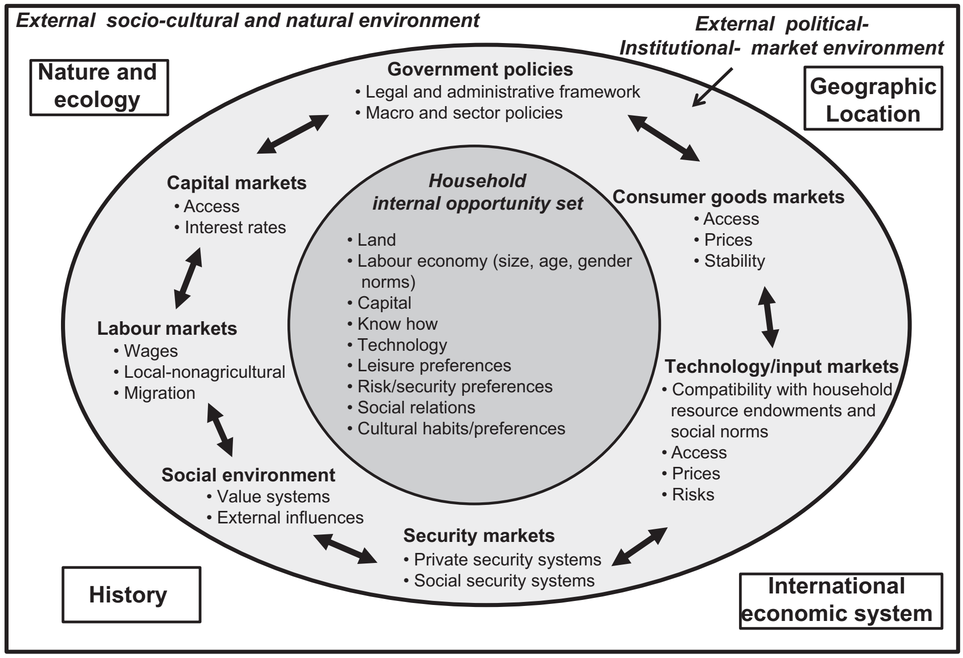


Fig. 3.1. General conceptual framework for explaining household energy choices (Adapted from Bruntrup and Heidhues [36]).

ladder depend on biomass resources which are, especially in rural areas, collected by the households themselves. Commercial fuels are ranked higher on the ladder and need to be purchased in the market. A move up the energy ladder hence involves to some degree a similar process from self-sufficiency towards market dependence. A clear distinction between market dependence for agricultural produce and energy carriers is the fact that households predominantly depend on markets as consumers for energy carriers, while many farm households are both consumers and producers on agricultural good markets.

The framework distinguishes between three categories of influencing factors: (i) the country external environment shaping the boundaries within which a society has to function (such as climate, geographic location and history); (ii) the decision context reflecting household external and country internal factors based on the institutional, political and market situation of a specified location (factors include capital market, government policies, consumer markets etc.); and (iii) the household opportunity set representing a group of household internal factors based upon the characteristics and factor endowment of the household. The interaction between factors across categories determines the decision environment, which is unique for each individual household. The key factors shaping the energy decision environment identified in the literature will be discussed next following the structure of Bruntrup and Heidhues' [36] framework.

The household *opportunity set* is the building block of a household's livelihood strategy. It determines the capacity a household has to reduce its vulnerability and restricts or broadens their window of opportunity. Important for the opportunity set is the household endowment. Human capital is considered to be essential in the energy decision process [11,16]. Not only does this include education and knowledge, but also household composition characteristics such as labour availability, household size, age and gender. Lack of information regarding alternative energy sources and the benefits associated with the use of these alternatives is seen as a serious barrier for adoptation [14,37]. Higher levels of education cause households to use less biomass fuel possibly because their opportunity costs of biomass collection increase [38,39]. Increasing availability of household labour has been found by many researchers to be a determining factor especially in rural areas where collection of biomass plays an important role [17,18]. Larger households are found to be more likely to use multiple fuels instead of switching fuels [10,38].

Gender findings have mainly focused on the labour situation of women. The number of women in a household is assumed to specifically constrain a switch to modern fuels as they are mainly responsible for the collection of firewood [2]. The more women present in a household, the larger the availability of labour to fetch firewood. Women's income turns out to be an important determinant of modern fuel choice in a number of studies [16,40,41]. Not only opportunity costs of time, but also shifts in the gender power balance underlie this effect. Furthermore, household preferences based on traditions and cultural beliefs are found to influence fuel choice [7,16,28,41]. For instance, a study in rural Mexico by Masera et al. [7] find that people continue to use firewood even when they can afford to use modern fuels because cooking tortillas on LPG is more time consuming and negatively affects taste. Similarly, Indian households prefer to use wood stoves for baking traditional bread [1,42]. Heltberg [2] argues that traditional cooking techniques and taste preferences might make people prefer wood fuel, even in situations where wood fuel is as expensive as the available alternatives. Taylor et al. [43] study migrant families in Guatamala. Although migrants can afford LPG and indeed purchase LPG stoves, they rarely use these stoves because the adoption of this new fuel also requires changes in food preparation traditions. Guatemala's two staple foods, beans and corn, require many hours of cooking and gas is considered too expensive for long cooking processes. Lifestyle and other cultural factors have a strong influence on fuel choice as well [1,16]. Masera et al. [7] explain how LPG stoves function as status symbols in communities attracting people to (partially) switch to LPG. On the other hand, the social function of open fires should also not be underestimated. Besides cooking, they are used for both lighting and heating the dwelling. Alternative fuels do not serve this multiplicity of purposes.

The market environment is an important feature of the *decision context* in the original framework. Access to, prices and

stability of consumer markets are factors that are discussed in the energy literature as well. The fuel market structure plays an important role in the physical access to a fuel. Reliability of supply, the structure of the distribution network and the number of distributors were found to impact fuel choice [11,22]. Furthermore, transaction costs involved in purchasing a fuel, such as the effort required from households for transportation, collection and buying in terms of time and distance to markets, influence a household's access and are found to impact their choice [22]. Peng et al. [39] discuss the differences between residents living in mountainous, hilly and plain areas. They find that people living on the plains have a larger variety of options to choose from, which is related to the accessibility of the area. Generally, the problem of access to modern fuel is more intense in rural areas, particularly in remote and low population density areas where the distribution of modern fuels is either insufficient or unreliable [23].

The effect of fuel prices on fuel choice is not well understood. Some scholars suggest that prices are the main factor restricting a household to move to modern fuels, while others find fuel prices rarely affecting fuel selection [12]. An interesting finding of Sathaye and Tyler [40] is that when considering relative fuel prices, poor households appear to pay more for their fuels on an energy content basis than higher income households. Leach [5] suggests that energy prices more often promote shifts between fuels amongst households already using several fuels. Households who own the necessary equipment can move forth and back on the ladder when facing price chances or supply failure. This suggests that it is not the fuel price per se hindering transition, but the acquisition of modern fuel equipment, also referred to as the 'stove barrier' [5,7,8,40,44,45]. Technology markets selling the appropriate equipment at affordable prices thus play an important role. Edwards and Langpap [45] indicate that access to credit, due to its effect on the ability of the household to finance the purchase of a gas stove, play a significant role in determining the quantity of wood consumed by Guatemalan households. Israel [41] suggests, based on her findings, that policies designed to encourage households to switch to a cleaner fuel might target either subsidies or credit access for the purchase of the necessary durable goods. Another constraint related to fuel prices is the problem that electricity and bottled gas must be paid for in relatively large lump sums, while fuel wood and kerosene can be purchased in small amounts on a daily basis. Avoiding lumpy payments is an important household strategy for the poor even though they might end up paying much more for their energy supplies [5].

Intervention strategies by governments have had mixed results on the energy choice behavior of households and rarely manage to effectively target the population the intervention was meant for [46]. For example, the rationing of energy carriers in Hyderabad discouraged people from choosing kerosene as their main energy carrier. The ration was not sufficient, distribution was not reliable, and the ration cards did not reach all members of society [46]. The "butanisation" program in Senegal, on the other hand, aimed at encouraging households to switch to LPG through government subsidies, achieved a remarkable success [47].

Energy access is closely related to location factors embedded in the *country external environment*. The geographical location determines the available type and quantity of biomass resources. Households living in colder climates use more energy than others in warmer climates [23], which may make switching to alternative fuels more costly. Abundant availability of fuel wood that can be collected free of monetary costs may limit the need for households to switch to alternative and more costly fuels [10]. Furthermore, urbanization is assumed to drive inter-fuel substitution [5]. As urban areas expand, various changes occur in access to fuels, infrastructure, market diversity, housing choices, and household activities, thereby influencing fuel choices [40,42]. Rural areas, on the contrary, typically face a less dynamic situation and are confronted with slower movements or even a status quo situation.

4. Drivers of the energy transition

Based on the household decision environment, this section elaborates on the specific factors influencing fuel switching behaviour, distinguishing between the household opportunity set, the household decision context, and the country external environment. The method used for this evaluation is a qualitative meta-analysis[2] based on seven revealed preference studies [48], which we were able to identify in the literature and that analyzed the energy transition process using econometric tools, in particular multinomial logit models (MNL). MNL is a standard regression technique for assessing how different variables affect multiple fuel choices [10]. It therefore enables the systematic analysis of household switching behaviour between different types of fuels. The seven studies listed in Table 4.1 are found in the revealed preference literature on energy transitions and fuel switching using MNL in a developing country context.

All studies describe and analyze actual switching behaviour of households for cooking fuels, but differ in the set of cooking fuels analyzed. Categorization of fuels is used in two of the seven studies where solid/non-solid and no switching/full switching is used to describe the transition process. The categorization "solid" and "no switching" both refer to the use of biomass fuels only and "non-solid" and "full switching" refer to the use of modern forms of energy. The in-between stage indicates fuel stacking behaviour. The studies by Hosier and Dowd [4] and Heltberg [2] have included fuel combinations in their analysis and therefore allow for partial switching as well.

4.1. The household opportunity set

In all studies the socio-economic determinants in the form of household characteristics and factor endowment received most attention. These factors lead us to identify distinct groups of households based on fuel choice behaviour. An overview of these factors is presented in the upper part of Table 4.2.

Income is the most frequently used indicator to distinguish households from each other. It is also the most important influencing factor related to fuel switching according to the energy ladder theory. The relationship between income and fuel switching is therefore addressed in all the studies. All studies confirm the relationship between income and the move towards more advanced fuels to a certain extent. Mekonnen and Kohlin [13] find that households with higher expenditure levels are less likely to use solid fuels only, but cannot attribute the switch from non-solid fuels to a mix of solid and non-solid fuels to household expenditures only. Heltberg [2] shows that household expenditure is insignificant for fuel switching in rural areas. Hence, income does not appear to be the key factor it was expected to be according to the energy ladder model.

The way households earn their income characterises their economic position. On the one hand, in urban areas, Rao and

[2] Meta-analysis is the evaluation of the findings of empirical studies, helping to extract information from often large datasets in order to support a more comprehensive assessment [49]. It is a method of synthesizing the results of multiple studies that examine the same phenomenon through the identification of common effects. It enables researchers to explain differences in outcomes found in single studies on the basis of differences in underlying assumptions, standards of design and/or measurement [50].

Table 4.1
Overview of the studies reviewed in the meta-analysis.

No	Author(s)	Countries	Response variable: multiple fuel choices	Rural/urban area	Data source	Ref.
1	Heltberg	Guatamala	Firewood/firewood and LPG/LPG/ charcoal and LPG	Rural and urban	ENCOVI National Survey of Living Conditions 2000	[2]
2	Rao and Reddy	India	Firewood, LPG, kerosene and other	Rural and urban	National Sample Survey 1999–2000. 118,000 households	[3]
3	Hosier and Dowd	Zimbabwe	Gathered fuel wood, purchased fuel wood, transition fuels, kerosene, electricity	Rural and urban	Household energy survey 1984	[4]
4	Heltberg	Brazil, Ghana, Vietnam Guatamala, India, Nepal, Nicaragua, South Africa,	No switching/partial switching/full switching	Rural and urban	Living standard measurement survey 1996–2000	[10]
5	Mekonnen and Köhlin	Ethiopia	Solid (fuel wood and charcoal), non solid (kerosene and electricity) or a combination of both	Urban	Household panel data 2000–2004, 1500 households in each survey	[13]
6	Ouedraogo	Burkina Faso	Firewood, charcoal, kerosene, LPG, other solid fuels	Urban	Household expenditure survey 1996. 1008 households	[51]
7	Pundo and Fraser	Kenya	Firewood, charcoal, kerosene	Rural	Household survey Kisumu 2001, 410 households	[52]

Reddy [3] find that income derived from wages or salaries has a positive impact on the probability of using LPG instead of other fuels. On the other hand, farm households are less likely to use LPG only [2]. The irregular and variable income flows derived from agricultural work or informal selling of goods could prohibit the regular consumption of modern energy [15] and restrict fuel switching. These results are in line with the expectation that households with a stable regular income are better able to rely on commercial fuels for their energy consumption, in this case LPG.

Capital assets are linked to a household's wealth as well as to its living conditions. In turn, living conditions might enable the use of certain cooking technologies and their respective fuels. House ownership is also one of the factors examined in the existing studies. Being the owner of a house does not imply higher purchasing power than a tenant, but it does provide freedom of space management in the house [51]. Tenants must adhere to occupancy rules, possibly limiting their energy options [52]. Ouedraogo [51] finds household ownership to increase the probability of using firewood compared to tenants. This could be a very specific result based on the situation in Ouagadougou, where it is common for tenants to live in dwellings called 'celibaterriums', i.e., sharing a yard with several houses with little space for wood-energy storage. However, Pundo and Fraser [52] find a similar result showing that tenants are more likely to use kerosene or charcoal over wood. Their results are based on rural data where it is most likely not an issue of space or lack of available biomass, but rules and regulations of tenancy contracts. House size measured by the number of rooms has been associated with a move away from fuel wood towards exclusive LPG use [2]. This is an indicator showing how wealth influences fuel switching. Similarly, having access to tap water was found to significantly reduce the probability of using solid fuels only and increase the probability of using non-solid fuels [10]. Finally, households who only have outdoor cooking facilities are more likely to use firewood than those with indoor facilities [51].

Human capital is also an important asset and refers to both the quantity and quality of available labour in the household, including educational level, knowledge and professional skills. Education is seen as an important determinant of fuel switching behaviour. All studies except Pundo and Fraser [52] find positive effects of education on the probability that households use modern commercial fuels such as LPG and Kerosene. This can be explained by the increasing opportunity costs of fuel collection time at higher levels of education and the increased level of awareness of the negative effects of wood and charcoal use on health [10]. The effect of education on fuel switching appears to be the same in both rural and urban areas [2,3,10]. Increasing family sizes suggest that there is abundant labour available for fuel collection, which limits the need to move to modern fuels purchased in markets. Rao and Reddy [3] mention that larger households in developing countries are often related to lower incomes, hence explaining their limited capacity to purchase commercial fuels. In order to feed a large family one needs a larger amount of fuel. Energy consumption and usage cost of a given stove are significantly lower for smaller households of 1–3 persons [53]. Using fuel wood is cheaper due to its lower consumption rate per unit of time compared to kerosene and charcoal, prohibiting large families to switch. Heltberg [10] and Pundo and Fraser [52] find no significant relationship between fuel switching and family size, contrary to Mekonnen and Kohlin [13], Ouedraogo [51] and Rao and Reddy [3] who find that larger households are less likely to choose non-solid fuels over solid fuels. Heltberg [2] confirms that smaller households are more likely to use the non-solid fuel LPG as their only fuel, but finds a switch from wood to the transition combination of wood and LPG unrelated to household size. Another contrasting finding is that of Hosier and Dowd [4], who find that larger households are more likely to move away from fuel wood towards kerosene.

Within the household labour economy, women are often responsible for cooking and collecting firewood. On the one hand, a high share of females in the household increases the supply of collection and cooking labour time and reduces the need to abandon time-consuming fuel wood sources. On the other hand, women are most directly affected by the negative effects of firewood use and switching to other fuels can improve their livelihood situation considerably. A larger number of females in the household could translate into a better bargaining position inducing power over fuel choices. Heltberg [2] finds that a high share of females in the household significantly reduces the likelihood of single fuel LPG use, while it does not affect the choice between only wood and joint wood and LPG. Mekonnen and Kohlin [13] do not identify an effect of the share of women in the household on fuel choice. They find, however, that female headed households are more likely to use either solid fuels or a mix as their main fuel. Rao and Reddy [3] find an opposite trend: households headed by women are more likely to choose modern

Table 4.2
Driving forces underlying energy choice behaviour identified in the literature.

	Heltberg [2]	Rao and Reddy [3]	Hosier and Dowd [4]	Heltberg [10][z]	Mekonnen and Kohlin [13]	Ouedraogo [51]	Pundo and Fraser [52]
Household opportunity set							
Human capital							
Education (respondent)	x[*(b,d),**(c)]	x[*(f,g,h)]		x[**(n),*(o)]	x[**(p,q)]	x[**(u)]	x[a]
Education (spouse)							x[**(v)]
Household size	x[**(d)]	x[**(f,g,h)]	x[*(l)]	x[**(n,o)]	x[*(p,q)]	x[**(r,s,u)]	x[a]
Household size squared		x[*(f,g,h)]			x[**(p,q)]		
Share of females in the household	x[**(b,d)]				x[a]		
Wealth and income indicators							
Indoor water				x[**(n),*(o)]			
Number of rooms in house	x[**(c)]						
Ownership of dwelling						x[a]	x[*(v)]
Type of dwelling							x[**(v,w)]
Cooking facility (external)						x[*(r,t)]	
Household income			x[*(j,k,l,m)]			x[*(r,s,t,u)]	
Household expenditure	x[*(b),**(c)]	x[*(f,g),**(h)]		x[**(n),*(o)]	x[**(p)]		
Square of per capita expenditure		x[**(f,g),*(h)]					
Other household characteristics							
Age		x[*(f),**(g,h)]			x[*(p)]	x[*(t)]	x[a]
Age of the Spouse							x[a]
Sex of the household head		x[**(f),*(g,h)]			x[**(p,q)]	x[a]	
Household labour activities	x[**(b,d),*(c)]	x[x]					x[a]
Cultural background and food preferences							
Religion of the household head		x[**(f,g,h)]				x[**(r,s,t)]	
Social group		x[*(i)]					
Indigenous	x[**(b),*(c)]						
Frequency of cooking Tô						x[**(r)]	
Frequency of cooking Rice						x[*(r,s,u)]	
Category of food prepared							x[**(w)]
External decision context							
Access to fuels							
Electricity	x[**(c),*(d)]			x[**(n),*(o)]		x[*(r),**(u)]	
Community distance to firewood	x[a]						
Difficulty of collecting firewood			x[**(j,l)]				
Fuel prices							
Wood price	x[*(b)]				x[*(q)]		
Charcoal price					x[a]		
Kerosene price	x[**(d)]				x[*(p,q)]		
Electricity price					x[a]		
LPG price	x[**(e)]						
Ratio of unit price of kerosene and electricity			x[*(m)]				
External environment							
Location	x[y]	x[y]	x[y]		x[y]		
Time					x[**(p,q)]		

Explanatory note:

[*] Significant positive effect on energy choice.
[**] Significant negative effect on energy choice.
[a] No significant effect on energy choice.
[b] Purchased wood (base gathered wood).
[c] Transition fuels (base gathered wood).
[d] Kerosene (base gathered wood).
[e] Electricity (base gathered wood).
[f] No switching rural and urban (base partial switching).
[g] Full switching rural and urban (base partial switching).
[h] LPG urban (base LPG and Woodfuel).
[i] Wood urban (base LPG and Woodfuel).
[j] LPG rural (base LPG and Woodfuel).
[k] Wood rural (base LPG and Woodfuel).
[l] LPG (base others).
[m] Charcoal (base others).
[n] Firewood (base others).
[o] Kerosene (base others).
[p] Charcoal (base firewood).
[q] Kerosene (base firewood).
[r] LPG rural and urban (base wood).
[s] Kerosene rural and urban (base wood).
[t] Other fuels rural and urban (base wood).
[u] LPG rural (base wood).
[v] Solid fuels (base non-solid).
[w] Mix of solid and non-solid fuels (base non solid).
[x] The paper distinguishes a variety of labor activities with different statistical impacts on energy choice. For readability reasons they have not been included in the table.
[y] A large number of specific location dummies have been included in the studies with both negative and positive effects on energy choice. For readability reasons they have not been included in the table.
[z] The paper looks at results from 8 different countries. For readability the general findings amongst the 8 countries have been included.

fuels over traditional fuels. This confirms the assumption that women will choose fuels that improve their collecting and cooking conditions. However, a large share of female headed households belongs to the poorest segments of society, which limits their access to modern fuels. This could explain the findings of Mekonnen and Kohlin [13].

The age of the household head can also lead to two opposing effects. On the one hand, the age of the household head functions as an indicator for the household's life cycle. The further a household moves up in its lifecycle, the wealthier it becomes and the more likely it has been able to accumulate financial assets, allowing them more financial freedom. On the other hand, older household heads may be more conservative, restraining them to move away from their current practices. Mekonnen and Kohlin [13] and Ouedraogo [51] find a positive relationship between age and the use of solid fuels as the main fuel for cooking. Mekonnen and Kohlin [13] are unable to find an effect for age on the choice between non-solid fuels and a mix of solid and non-solid fuels. In the studies no evidence is found for a negative relationship between age and the use of solid fuels.

Traditions, habits and religion have created specific lifestyles, which are deeply rooted within societies. The social group that people belong to, based on their culture or religion serves important security and communal purposes and can play a crucial role in the behaviour of households. Indigenous ethnic groups in urban Guatemala have fuel portfolios that differ significantly from non-indigenous groups, resulting in a much higher likelihood of using fuel wood only [2]. Two possible reasons explaining this finding are: (i) a traditional lifestyle and other cultural factors may lead to a preference for fuel wood among indigenous groups; (ii) indigenous groups are less integrated into the formal economy and find it therefore harder to access or afford LPG [2]. The two main religions found in India, Hinduism and Islam, were included and distinguished in the study of Rao and Reddy [3]. They find that Islamic households in rural areas are less likely to use LPG than firewood. Muslims are a minority group in India, which could be a barrier to access modern forms of energy.

Cultural practices can also be an explanation for the observed behaviour. Meals that are traditionally cooked on fire can steer preferences to continued use of firewood. Masera et al. [7] find that fuel stacking can among other reasons be explained by the preference and convenience of certain fuels over others for specific forms of cooking. Ouedraogo [51] shows in his study that the frequency of cooking 'tô' increases the likelihood of using fuel wood. Tô is a meal which is rooted in the cooking culture of Ouagadougou. Local cereals used for preparing tô are less expensive than rice. An increase of the frequency of households cooking rice reduces the likelihood of using firewood.

4.2. The household decision context

In the reviewed studies, less attention is paid to the household decision context, which is based on the household external or country internal environment. Factors include issues such as access to energy and price levels (see the middle part of Table 4.2). Resource scarcity induces access problems, resulting in either higher monetary costs or opportunity costs of time. Hosier and Dowd [4] argue that wood scarcity is a driving force for the likelihood of households to use another fuel than wood. It implies longer distances to collect firewood and easier switches to other fuels. A household's perception of the biomass pressure in its surroundings is also found to be influencing fuel switching. Households who do not perceive fuel wood as difficult to collect (a proxy for resource scarcity in the area) prefer wood-based fuels to a commercial fuel option [4]. Heltberg [2] looks at the impact of community distance to fuel wood. Longer distances imply pressure on existing biomass resources and increase the opportunity costs of collecting fuel wood. However, he was unable to find a relationship between distance to fuel wood and fuel switching.

Electricity access is found to be positively associated with fuel switching for cooking [2,10]. In urban areas, it results in a significantly smaller probability of using wood only and a significant increase in the likelihood of using more LPG. In rural areas it causes a significantly larger probability of consuming only LPG [2]. Barnes et al. [6] suggest two explanations for the electricity-LPG link: (i) where electricity is available, fewer barriers constrain other modern fuels as well, and (ii) availability of lighting and other appliances spurs people to a greater acceptance of modernity and modern fuels. Ouedraogo [51] finds households moving up the energy ladder when using electricity as the 'source of lighting energy'.

Beside physical access, fuel prices can influence the accessibility of fuels on the market. Prices matter to some extent for fuel switching [4,13]. High LPG prices increase the consumption of wood in rural areas where it dominates rural cooking with LPG being no more than an occasional complement. In urban areas where LPG dominates urban cooking and wood is a complement, high firewood prices induce an increase in the probability of using LPG only [2]. This illustrates the local impact of prices on choice behaviour.

4.3. The country external environment

The location where the household resides is key to several influential determinants of the country's external environment. Urbanisation is one of the variables that has been linked to energy transitions from the early days onwards (bottom part of Table 4.2). Hosier and Dowd [4] identify urban locality as an important driver of energy transitions. Households in urban areas are more likely to utilize higher quality energy carriers than comparable households in rural areas [2,4]. Heltberg [10] finds that in both rural and urban areas the same variables are significant, but that the magnitude of the effect often differs. This implies that similar mechanisms drive fuel switching in urban and rural areas, but in different degrees. He assumes that the lower levels observed for fuel switching observed in rural areas must be because of lower rural levels of the triggering variables. Furthermore, larger cities are assumed to provide a better enabling environment for modern fuels. Mekonnen and Kohlin [13] find that households residing in Addis Ababa, the capital of Ethiopia, are more likely to choose non-solid fuels than households in smaller towns. They ascribe this finding to better access to electricity and kerosene, higher awareness levels, and learning from others. Mekonnen and Kohlin [13] are the only ones who use panel data. This enabled them to include the factor time in their analysis. They find that households are more likely to have non-solid fuels as their main fuel in 2004, compared to 2000. This suggests a shift towards non-solid fuels over time. Whether the effect found is only a matter of time is disputable. Changes over time in the decision context in which people operate, not accounted for in the model could be picked up by this variable as well.

5. Conclusions

In this paper, we studied energy transitions in a developing country context through an assessment of the energy ladder model and empirical studies on fuel switching behaviour. The energy ladder remains somewhat of a myth, not observed empirically. Instead of a linear pattern showing fuel displacement at higher income levels, the ongoing transition process is best described by multiple fuel use representing an energy portfolio.

This energy stacking behaviour can be seen as a livelihood strategy through which households cope with irregular income flows, protect themselves from unstable markets and hold on to their cultural practices, while benefitting to some extent from modern fuels.

The decision to move from universal reliance on biomass fuels to partial or full market dependence takes place in a household decision environment. Such an environment is complex and multidimensional, stressing the need to look beyond income as the prime driving force behind fuel switching. We described a conceptual framework for the analysis of household decision behaviour based upon three layers of factors: (i) the household external biophysical environment, (ii) the household external political and institutional-economic decision context and (iii) the household internal opportunity set. This framework provides a more comprehensive and structured tool to assess household behaviour in an energy transition context and identify policy priority areas for fuel switching behavior. Several factors from this framework have been identified influencing fuel switching in the available empirical studies. Among those are household internal factors such as human capital, the household labour economy, cultural background and customs, and household characteristics such as age, labour activity, and income and household external factors such as access to fuels and price levels of fuels. We clearly show that energy switching behaviour depends on more than income only as suggested by the energy ladder.

Based on our review, we are unable to conclude which of the different layers is most important in explaining fuel switching behaviour, mainly due to the fact that existing research has put most emphasis on describing household behaviour through the socio-economic characteristics of the household opportunity set. Relatively little attention has been devoted to the decision context and the external environment, even though factors such as consumer markets and existing government policies are expected to play an important role in the decision-making behaviour of households regarding fuel choices. Inclusion of such elements in the analysis could provide us with further insight in changing existing behaviour towards more sustainable energy carriers, for instance with the help of policy instruments. So far the focus in the existing literature has been mainly on conventional energy sources in developing countries, disregarding the potential role of renewable energy technologies in the energy transition process. Renewable energy technologies serve as promising alternatives to conventional modern energy sources. Not only are these technologies expected to provide increased energy security, they also reduce environmental pressure, improve personal health and enhance development potential in a sustainable, low carbon way. The inclusion of renewable energy technologies in energy transition studies asks researchers to no longer focus on fuels only, but also understand the interaction between fuels and energy carriers like cooking stoves and the impact of the decision environment on the choice for a specific combination of the two. Here, also product specific preferences of households, for instance for cooking appliances, are key for the adoption of the available products. We therefore emphasize that research on energy transitions also combine social characteristics with a better understanding of preferences for such products.

Acknowledgement

This work was financially supported by the Netherlands Ministry of Foreign Affairs through the IS-Academy on Renewable Energy in Africa (RENEW) coordinated by the Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, The Netherlands.

References

[1] International Energy Agency, World Energy Outlook. Energy for cooking in developing countries. Paris: International Energy Agency; 2006.
[2] Heltberg R. Factors determining household fuel choice in Guatamala. Environment and Development Economics 2005;10:337–61.
[3] Rao MN, Reddy BS. Variations in energy use by Indian households: an analysis of micro level data. Energy 2007;32:143–53.
[4] Hosier RH, Dowd J. Household fuel choice in Zimbabwe: an empirical test of the energy ladder hypothesis. Resources and Energy 1987;9:347–61.
[5] Leach G. The energy transition. Energy Policy 1992;20:116–23.
[6] Barnes DF, Floor WM. Rural energy in developing countries: a challenge for economic development. Annual Review of Energy and Environment 1996;21:497–530.
[7] Masera OR, Saatkamp BD, Kammen DM. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. World Development 2000;28:2083–103.
[8] Campbell BM, Vermeulen SJ, Mangono JJ, Mabugu R. The energy transition in action: urban domestic fuel choices in a changing Zimbabwe. Energy Policy 2003;31:553–62.
[9] Gallagher KS. Limits to leapfrogging in energy technologies? Evidence from the Chinese automobile industry Energy Policy 2006;34:383–94.
[10] Heltberg R. Fuel switching: evidence from eight developing countries. Energy Economics 2004;26:869–87.
[11] Farsi M, Filipini M, Pachauri S. Fuel choices in urban Indian households. Environment and Development Economics 2007;12:757–74.
[12] Hiemstra-van der Horst G, Hovorka AJ. Reassessing the "energy ladder": household energy use in Maun, Botswana. Energy Policy 2008;36:3333–44.
[13] A Mekonnen, G Kohlin, Determinants of household fuel choice in major cities in Ethiopia. Working Papers in Economics No. 399. University of Gotenburg; 2008.
[14] Schlag N, Zuzarte F. Market barriers to clean cooking fuels in Sub-Saharan Africa: a review of literature. Stockholm Environment Institute; 2008.
[15] Davis M. Rural household energy consumption: the effects of access to electricity: evidence from South Africa. Energy Policy 1998;26:207–17.
[16] Gupta G, Kohlin G. Preferences for domestic fuel: analysis with socio-economic factors and rankings in Kolkata, India. Ecological Economics 2006;57:107–21.
[17] Arnold JEM, Kohlin G, Persson R. Woodfuels, livelihoods, and policy interventions: changing perspectives. World Development 2006;34:596–611.
[18] Cooke P, Kohlin G, Hyde W. Fuel wood, forests and community management evidence from household studies. Environment and Development Economics 2008;13:103–35.
[19] Hosier RH, Kipondya W. Urban household energy use in Tanzania: prices, substitutes and poverty. Energy Policy 1993;21:454–73.
[20] Bhagavan MR, Giriappa S. Biomass, energy and economic and natural resource differentiation in rural Southern India. Biomass and Bioenergy 1995;8:181–90.
[21] Brouwer R, Falcao MP. Wood fuel consumption in Maputo, Mozambique. Biomass and Bioenergy 2004;27:233–45.
[22] B Mirza, R Kemp. Why rural rich remain energy poor. UNU-MERIT Working Papers; 2009.
[23] Elias RJ, Victor DG. Energy transitions in developing countries: a review of concepts and literature. Progam on energy and sustainable development. Stanford University; 2005.
[24] Karekezi S, Majoro L. Improving modern energy services for Africa's urban poor. Energy Policy 2002;30:1015–28.
[25] Martins J. The impact of the use of energy sources on the quality of life of poor communities. Social Indicators Research 2005;72:373–402.
[26] Maconachiea R, Tankob A, Zakariyac M. Descending the energy ladder? Oil price shocks and domestic fuel choices in Kano, Nigeria Land Use Policy 2009;26:1090–9.
[27] Wickramasinghe A. Energy access and transition to cleaner cooking fuels and technologies in Sri Lanka: issues and policy limitations. Energy Policy 2011;39:7567–74.
[28] Foley, G Photovoltaic applications in the rural areas of developing world. World Bank Technical Paper 304, Washington DC; 1995.
[29] Soussan J, O'Keefe P, Munslow B. Urban fuelwood challenges and dilemmas. Energy Policy 1990;18:572–82.
[30] ESMAP. Household energy strategies for urban India: the case of Hyderabad. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington D.C.; 1999.
[31] Murphy JT. Making the energy transition in rural east Africa: is leapfrogging an alternative? Technological Forecasting and Social Change 2001;68:173–93.
[32] Takama T, Tsephel S, Johnson FX. Evaluating the relative strength of product-specific factors in fuel switching and stove choice decisions in Ethiopia: a discrete choice model of household preferences for clean cooking alternatives. Energy Economics 2012;34:1763–73.
[33] Wall G, Gong M. On exergy and sustaianable development—Part 1: conditions and concepts. Exergy, an International Journal 2001;1:128–45.
[34] Rosen MA, Dincer I, Kanoglu M. Role of exergy in increasing efficiency and sustainability and reducing environmental impact. Energy Policy 2008;36:128–37.
[35] Dincer I, Rosen MA. Thermodynamic aspects of renewables and sustainable development. Renewable and Sustainable Energy Reviews 2005;9:169–89.

[36] M Bruntrup, F, Heidhues. Subsistence agriculture in development: its role in process of structural change. Research in Development Economics and Policy Discussion Paper 1/2002, Hohenheim, Institute of Agricultural Economics and Social Sciences in the Tropics and Subtropics; 2002.
[37] ESMAP. Household energy use in developing countries: a multi country study. Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP), Washington, DC; 2003.
[38] DF Barnes, K Krutilla, HF William. The urban household energy transition: social and environmental impacts in the developing world. Resources for the Future, Washington D.C.; 2005.
[39] Peng W, Hishamb Z, Pan J. Household level fuel switching in rural Hubei. Energy for Sustainable Development 2010;14:238–44.
[40] Sathaye J, Tyler S. Transitions on household energy use urban China, India, the Philippines, Thailand and Hong Kong. Annual Review of Energy Environment 1991;16:295–335.
[41] Israel D. Fuel choice in developing countries: evidence from Bolivia. Economic Development and Cultural Change 2002;50:865–90.
[42] Malhotra P, Dutta S, Pal RC, Sharma S, Ramana PV. Rural energy matters: the Dhanawas experience. New Delhi: The Energy Research Institute; 2003.
[43] Taylor MJ, Moran-Taylor MJ, Castellanos EJ, Elías S. Burning for sustainability: biomass energy, international migration, and the move to cleaner fuels and cookstoves in Guatemala. Annals of the Association of American Geographers 2011;101:918–28.
[44] Gebreegziabher Z, Mekonnen A, Kassie M, Köhlin G. Urban energy transition and technology adoption: the case of Tigrai, northern Ethiopia. Energy Economics 2012;34:410–8.
[45] Edwards JHY, Langpap C. Startup costs and the decision to switch from firewood to gas fuel. Land Economics 2005;81:570–86.
[46] Kowsari R, Zerriffi H. Three dimensional energy profile: a conceptual framework for assessing household energy use. Energy Policy 2011;39:7505–17.
[47] Denton F. Reducing the gap between projects and policies: a comparative analysis of the "butanisation" programme in Senegal and the multifunctional platform (MFP) experience in Mali. Energy for Sustainable Development 2004;2:17–29.
[48] AM Freeman III. The measurement of environmental and resource values: theory and methods, resources for the future, Washington D.C., 2003.
[49] Glass GV, McGaw B, Smith ML. Meta-analysis in social research. Beverly Hills: Sage Publications; 1981.
[50] Wolf FM. Meta-analysis. Beverly Hills: Sage Publications; 1986.
[51] Ouedraogo B. Household energy preferences for cooking in urban Ouagadougou, Burkina Faso. Energy Policy 2006;34:3787–95.
[52] Pundo MO, Fraser GCG. Multinomial logit analysis of household cooking fuel choice in rural Kenya: the case of Kisumu district. Agrekon 2006;45:24–37.
[53] Pachauri S, Mueller A, Kemmler A, Spreng D. On measuring energy poverty in Indian households. World Development 2004;32:2083–104.